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A Training Monitoring System for Cyclist Based on Wireless Sensor Networks

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Abstract
This paper presents a training monitoring system for cyclist that is based on the technology of wireless sensor networks (WSNs). A stable and reliable wireless cyclist monitoring system is vital to establish a smart and efficient sports management program. A training monitoring system has been developed and tested in a real cyclist training environment in a velodrome. The system is designed is such a way that the packet loss rate is minimum. Using TelG mote as the basis, customized sensor nodes that function as a forwarder node and the relay nodes are developed to form the WSN. This WSN is linked to the cloud network on the Internet. The cloud network is then established and end users application for data accessing is designed. Several experiments have been conducted in a real scenario in a velodrome to measure the reliability of the system architecture. It is shown from the experiments that the proposed system is reliable even when the cyclist is moving at a high speed. The packet loss is less than 2% which does not give a huge impact to the data transmission.

***Keywords**: cyclist monitoring system, sensor networks, sports management*

1. Introduction

Cycling is one of the most popular sports in Malaysia and significant interests are given for this sport recently with the winning of a bronze medal by Malaysia team in the 2016 Olympic tournament in Rio, Brazil. The success of this sport is due to the elite level support provided by the Malaysia government with strong recreational and developmental programs. However, there is still a room for improvement in which latest technology can be exploited in order to achieve superior performance in the future. For instance, sports management wireless remote monitoring system has an important role in observing athlete's performance in his/her daily training. When monitoring the performance of athletes in the field, an applicable method of data transport must be determined in order to get the athlete's performance characteristics back to the coach. Therefore, the development of a stable and efficient wireless sports monitoring system is vital to establish a smart and efficient sports management program that can lead to quality outcomes.

Before advances in wireless sensor network (WSN) technologies, the normal practice to measure the performance of athletes in cycling training program is by using conventional stopwatch [1]. The results acquired from the training by using stopwatch is imprecise and uninformative. In addition, this method also has insufficient scientific support that proves training by using stopwatch can actually improve the performance of an athlete [2]. The current device used by the national cycling team to measure the speed, cadence, heart rate and power of the athletes during the training sessions is SRM (Schoberer Rad Messtechnik). The SRM is a power monitoring system that has been widely used to provide an accurate measurement of cycling power [3]. However, the data produced by SRM are stored first and must be transferred to a laptop or a personal computer (PC) through a universal serial bus (USB) cable to enable the trainer to observe and analyse the data. Hence, this process is quite time consuming and inefficient for the trainer to monitor their athletes performances continuously. A reliable wireless cyclist training monitoring system is really desirable in order for the national cycling team to improve their performance as well as to prevent over training. Since the training sessions of

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athletes are held in velodrome, the real size of velodrome as well as its shape must be taken into account when designing the whole system. The velodrome is 330m lengths and the track is banked with a certain degree of angle. The distance and the banked track of the velodrome are among factors that affect packets received rate during the transmission process. Consequently, it is important to consider these factors during the transmission process and design the system architecture for a wireless cyclist monitoring system that have minimum packet loss rate.

The implementations of WSNs for sports monitoring system have been proposed for many types of sports [2], [4], [5-8]. The authors in [4] have outlined the case for using iPhone in sports monitoring applications, specifically applied to cricket. A model was developed to collect the data generated by this device in a real-world usage. In addition, the paper also explored various aspects involved in the function capabilities exhibited in smartphones for the purpose of monitoring. A series of tests were performed to evaluate the developed monitoring software and it has been shown in [4] that the data capture is qualitatively similar with the previous work in evaluating bowling action [9]. Nevertheless, there is no quality of service (QoS) performance evaluation to measure the potential of the proposed model in [4]. Meanwhile the paper in [5] presents the use of a wearable sensor technology for single/multiple users with a framework that permits near real time data analysis for swimming monitoring system. Via simulation, the results indicates the workability of such devices to facilitate the athlete preparation and long term development planning. Since the work in [5] is based on simulation, the feasibility in a real time implementation has yet to be demonstrated. A mobile phone with Bluetooth technology is used by Aki Hankasuo et al in [6] to monitor the power, speed, and cadence of the bike. Bluetooth wireless technology is used for communication between the sensor module and the mobile phone. However, the biggest problem of using this technology is that the used of mobile phone is very high power consumption and Bluetooth technology is designed to have a very short distance transmission range.

A training monitoring system for cyclist based on Android application development was proposed in [7]. In this system, the required data such as cyclist’s heart rate and cadence are collected by sensor nodes before they are delivered to the mobile device mounted on the bicycle via wireless communication. The performance comparison in terms of setup time made with other applications such as Sport Pall, Heart Performance Rate and many more shows the feasibility of this system in monitoring cyclist’s performance. Nonetheless, the QoS performance of this system must be further investigated in order to measure the usefulness of the system in a real time environment. Another latest implementation of sports monitoring system was proposed in [8]. This work presents the details on the design and implementation of the smart E-bike monitoring system (SEMS) as a platform for the real time data acquisition from electrically-assisted bikes. The data such as the location and rider control data are fed online for data analysis and they can be accessed by the riders and for sharing on the social media. The implementation of the system on 30 bikes and the data collection for 10 months over real time trials in the United Kingdom have proved the stability and reliability of the system. However, further investigation is needed in order for the system to comply with the QoS requirement in wireless communication.

This work proposes a training monitoring system for cyclist that is based on the technology of WSN. The remainder of this paper is organised as follows; Section 2 elaborates on the proposed system while Section 3 presents the experimental setup and results of the experiments. The conclusion and recommendation for future work is finally made in Section 4.

2. Proposed Training Monitoring System for Cyclist

The scope of this research is to design a reliable system architecture with acceptable packet loss rate for cyclist training monitoring system in a real experimental test bed. The work includes the hardware design of sensor nodes and software development for sensor networks and cloud network. The general diagram for the cyclist training monitoring system is shown in Figure 1. The system consists of hardware components such as server, base station, sensor nodes and sensor devices. There are four types of nodes used in this research: sensor node, forwarder node, relay node and base station node. Based on the environment in a real cycling track in velodrome, data from the cyclist are collected and sent to the forwarder node. Then, data from the forwarder node is delivered to the base station through multiple hops of relay.

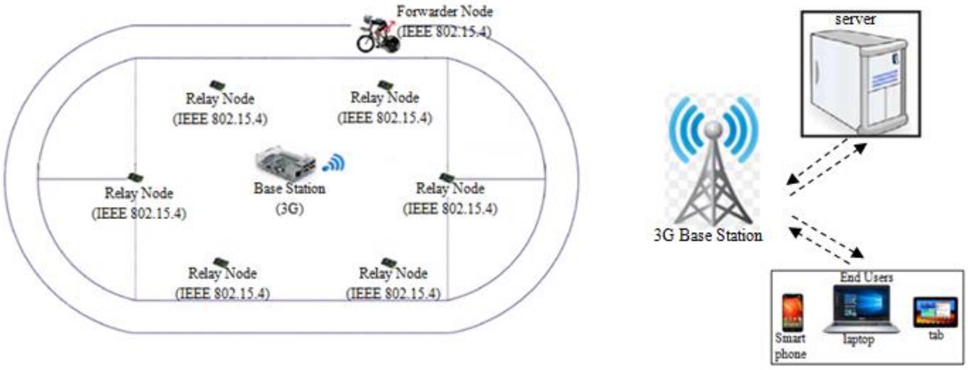

Figure 1. General diagram of a training monitoring system for cyclist

In this work, a customized wireless sensor node is developed based on the TelG mote and its operating system [10]. TelG mote has been successful developed and used discretely in Wireless Biomedical Sensor Network (WBSN) [10] and the Internet of Things application [11]. There are four main features of TelG node which are sensory unit, processing unit, wireless transceiver and power supply unit. Since TelG node is used as a forwarder node and relay nodes, it has to be customized by removing the sensing part so that it only acts as a router. By using the customized TelG node, the size of the new TelG node is reduced by thirty percent and at the same time the production cost is also decreased.

2.1. Network Framework

Figure 2 displays the cyclist training monitoring system network architecture. Acquired data from the sensor node are transferred to the cloud network and finally to the server based on the layered approach. Wireless sensor network forms a major part in the cyclist training monitoring system. The network serves as a medium to connect between the sensor nodes and the base station. Data are collected by the sensor nodes with sensing mechanism that are attached to a certain part of the bicycle or to the athlete's body. These data are sent using unicast communication to the forwarder node that is mounted on the cyclist's bicycle. The forwarder node broadcasts the data to the relay nodes that are located at certain locations in the velodrome. The task of the relay nodes is to route the data to the base station by using unicast communication. The base station then uploads the data on the cloud network, before they are kept in the server or any database. Meanwhile, the Internet forms the cloud network that allows the connection between the end users and the server. The internet protocol is used to interwork between cloud network and the WSN. The connection from the sensor nodes to the base station is using IEEE 802.15.4 protocol. TCP/IP protocol is used to relay the sensor data from the base station to the internet and transmits to the server.

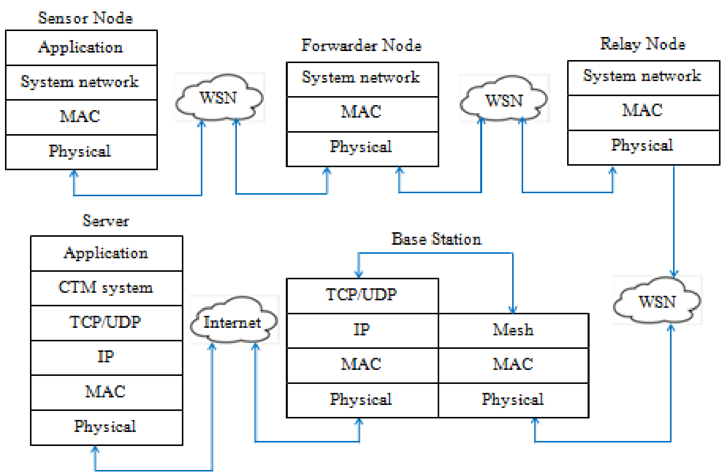

Figure 2. System network architecture

2.2. Communication in WSN

Wireless connection is used as a medium of communication in the system where the standard used is IEEE 802.15.4. The data transmission in the cyclist training monitoring system occurs in the wireless sensor network part. It involves the data transmitted from sensor nodes, the forwarder node and the relay nodes to the base station. Multihop data transmission technique has been applied in this system to ensure the data sent from the sensor nodes are received by the base station. Figure 3 shows the flow of data transmission in the system using multihop technique.

The sensor nodes are the nodes that are equipped with the sensing mechanism. Both the sensor node and the forwarder node are attached at the bicycle. Only one forwarder node is used to receive the data from the sensor node and forward the data to the relay nodes. Figure 4 describes the operation of the forwarder node in a flowchart. The forwarder node assigns a number to each received packet before it is being forwarded to the relay nodes. It is important to assign a sequence number to the packets to avoid any duplication. There are six relay nodes that are used in the proposed system. The relay nodes, which are based on the TelG mote, are located around the velodrome. The location of the relay nodes are determined based on the results from the measurement [12] to ensure a higher throughput during the data transmission process. Upon receiving the packet from the forwarder node, the relay node checks the sequence number of the packet to make sure that it is not a duplicate packet. If the packet has been received before, this received packet is rejected. Otherwise, it is transferred to the base station. Due to the fact that the transmission range of the sensor node is limited, the deployment of the relay nodes is important to route the data from the sensor nodes to the base station with minimum packet loss. Figure 5 shows the flowchart of the relay node's operation.

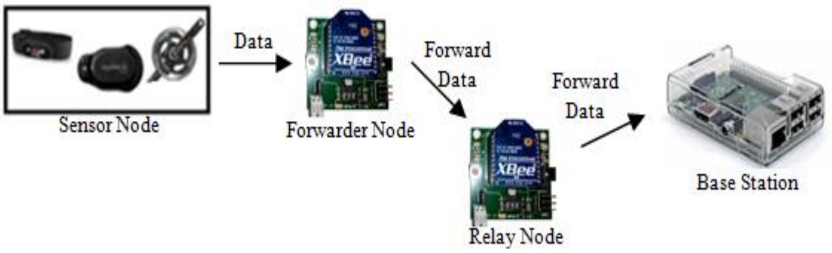

Figure 3. Multihop data transmission

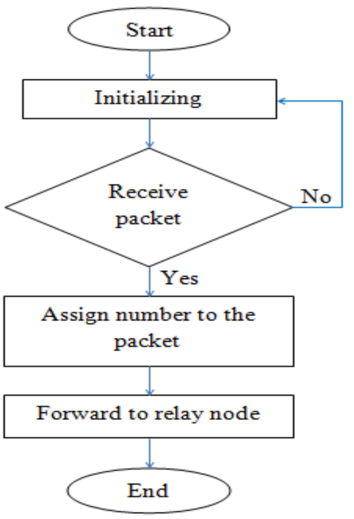

Figure 4. Operation of the forwarder node

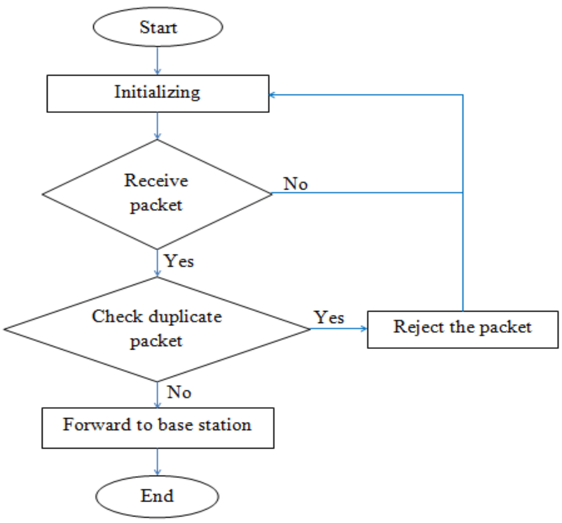

Figure 5. Operation of the relay node

Cloud network is a network that allows the data storage over the Internet so that it can be easily accessed at anywhere and anytime. The server is a part of cloud network that stores all the data obtained during the cyclist training. Internet connection is connected to the cloud network to enable the data acquired to be directly updated in the database. Once the data is in the server, it can be accessed by the athletes, trainers as well as sports scientist via application in mobile devices, smart phones, and web based computer. The cloud network and the WSN is connected via the base station. The task of the base station is to forward the data from the relay nodes to the server. The base station is built using the Raspberry Pi board as the main processor board. The XBee in the base station acts as a receiver that receives data from the relay nodes. It operates at 2.4 GHZ frequency band similar to the WSN mote. The Raspberry Pi is equipped with 3G connection and WSN connection. The Internet Protocol (IP) is used to interwork between the cloud network and WSN.

2.3. Application Development

The end users interface and the application to monitor the cyclist performance are designed using NetBeans IDE 7.1.2 platform and Java language. The training data that are forwarded from the base station are stored in the server according to the date of the training. There are five parameters that are observed in the actual implementation of the system, which are speed, cadence, temperature, heart rate and power. Users are able to choose which data to access and analyze according to the date of training. Furthermore, the data acquired can be saved in image format or in Microsoft Excel format based on end user's preference. Figure 6 shows an example of the graphical user interface (GUI) for data analysis developed for the cyclist training monitoring system. The trainers are also able to do the real time monitoring in which they can access and analyze the data during the training session. Figure 7 shows the GUI of the application for real time monitoring. A performance graph that is based on a real time will be displayed based on the selection made by the users.

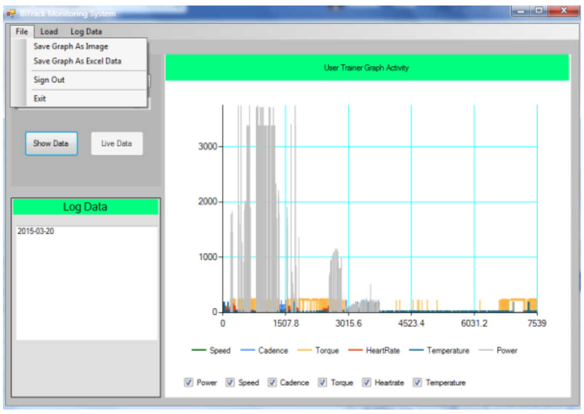

Figure 6. GUI for data analysis

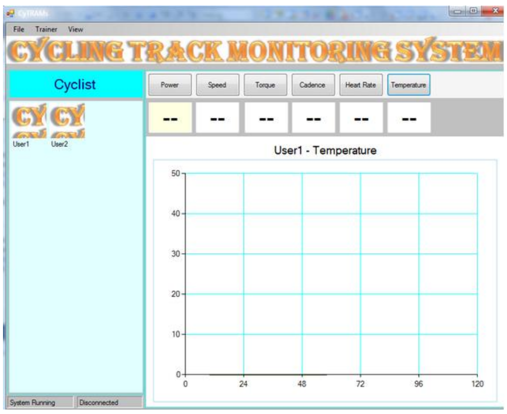

Figure 7. GUI for real time monitoring

3. Results and Analysis

The development of cyclist training monitoring system is carried out in a real test-bed to ensure the reliability of the system. The experiments are executed at at a velodrome in Cheras, Kuala Lumpur. The metric that is considered in the performance evaluation is packet loss rate. It is defined as the difference between the number of packets sent and the number of packets received at the destination. The lower the value of packet loss means the better the system is since more packets are successfully delivered to the destination. In our previous work in [12], we have conducted several performance measurements to investigate the factors that can affect the packet loss rate during data transmission. The factors that are taken into account during the measurements are distance between transmitter and receiver, height and angle of receiver, the mobility of the transceiver, transmission power of transmitter, as well as packet size and rate. Therefore, the architecture of the training monitoring system is designed based on the performance measurement results in [12], in such a way that the packet loss is minimum.

Figure 8 shows the system architecture of the cyclist training monitoring system that is based on the real size of a velodrome. Six relay nodes and one base station are used in the proposed system. Based on the measurements, the best distance between the transmitter and the receiver should not exceed 35m. With regards to the design illustrated in Figure 8, as long as the bicycle is still moving within the track, the distance between the transmitter and the receiver will not exceed 35m. In addition, the position of the receiver nodes which are relay nodes are fixed at 150cm from the ground according to the result obtained in [12], while the transmission power is set to 0dbm. During the real test-bed implementation, the value of some parameters is varied with time. Among the obvious parameters that are varied during the real test-bed implementation is the angle of the transmitter and the speed of the transmitter that is attached to the bicycle. In order to test the reliability of the system architecture, the effect of these two parameters are examined. Hence, two experiments are conducted which are Experiment A and Experiment B that investigate the effect of transmitter's angle and the bicycle's speed, respectively.

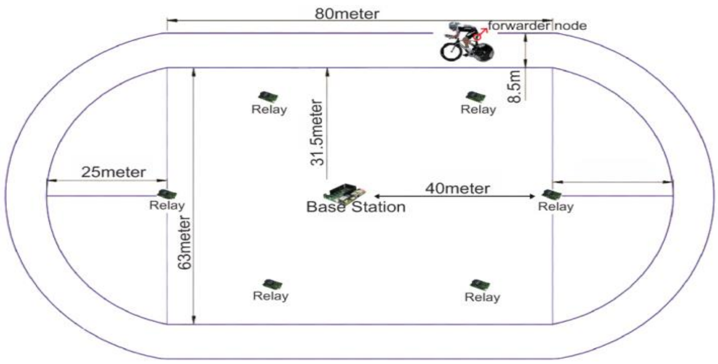

Figure 8. System architecture and setup

Table 1 shows the list of the parameters for both experiment A and B and their respective values. The designed cyclist training monitoring system is implemented inside the velodrome that is banked to a certain degree of angle. Since the angle of the forwarder node is changing according to the current position of the bicycle, it is essential to study the effect of the transmitter's angle to the number of packets received. The forwarder node has been programmed to transmit a packet in every 100 milisecond. This indicates that the transmission rate is 10 packets/second. The angle of the transmitter is varied at 22, 45, 60, 70, and 90 degrees. The speed of the bicycle that moves around the velodrome is 10km/hour and the measurement is repeated for two times for each angle.

Table 1. Parameters and Values for the Experiment

Parameters	Value (Experiment A)	Value (Experiment B)
Transmission rate	10 packets/second	2 packets/second
Size of packet	12 bytes	12 bytes
Speed of bicycle	10 km/hour	10, 20 and 30 km/hour
Number of packets transmitted	1188 packets	Depends on the bicycle's speed
Angle of the transmitter	22, 45, 60, 75 and 90 degrees	90 degrees

In the ideal state, the number of packets that should be received at the destination when the cyclist has completed one round of the velodrome is 1188 packets with regards to the speed of the bicycle, as well as transmission rate and the distance of the velodrome. Since the measurement is repeated for two times for each angle of the transmitter, the total packets that should be received is 2376 packets. Figure 9 shows the result of the measurement in terms of packet loss. The result shows that 470 (19.78%) packets are lost when the angle of the transmitter is fixed at 22 degrees, 391 (16.46%) packet loss when angle of the transmitter is fixed at 45 degrees, and 437 (18.39%) packets are dropped when the transmitter is tilted to 60 degree. When the angle of the transmitter is fixed at 70 and 90 degrees, the number of packets that are failed to reach the receiver is 399 (16.79%). From the results obtained, it can be observed that the angle of the transmitter does not give much effect to the number of packet loss. The experiment is then repeated with the angle of the transmitter is fixed at 90 degrees while the transmission rate for a packet to be transmitted is changed at 2 packets/second. The result shows that only 26 (1.09%) packets are lost during data transmission. As a conclusion, the transmission rate is among the parameters that affects the data delivery process. By setting the interval between successive transmissions to 500ms, the packet loss rate can be minimized.

The maximum speed that can be achieved by a professional cyclist during track cycling training or competition is approximately around 70km/hour. However, when the experiments are conducted in a real velodrome, the maximum speed that can be reached by a non-professional cyclist is around 30km/hour. Therefore, in this experiment, the speed of the bicycle is varied from 10km/hour to 30km/hour. The measurement is repeated two times for each speed. The transmission rate is fixed at 2 packets/second while the packet size for each packet is fixed at 12 bytes. Figure 10 shows the result of packet loss against the speed of the bicycle. It can be seen that the highest packet loss is obtained when the transmitter speed is 10km/hour. On the contrary, the lowest packet loss is when the speed of the bicycle is 30km/hour. This indicates that the higher the speed of the bicycle, the better is the data delivery ratio. The reason for this is explained as follows. It has been described before that the data from the forwarder node which is mounted on the bicycle is broadcasted to the relay nodes. Since there are six relay nodes that are positioned at the different locations around the velodrome, the possibility of the relay nodes to receive the data from the moving forwarder node is increased when the speed of the bicycle is higher. On the other hand, when the bicycle is moving with a low speed, there is a chance that the forwarder node's transmission range could not reach any six relay nodes in the velodrome. Hence, more packets are lost during the data delivery.

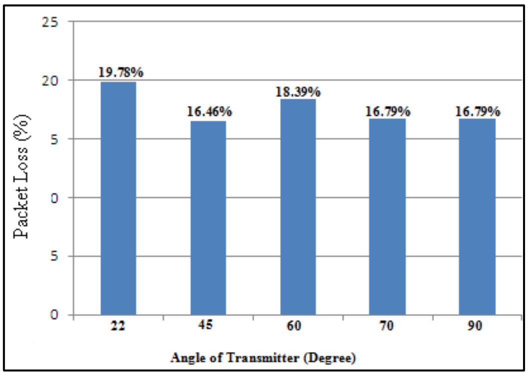

Figure 9. Packet loss rate against the angle of the transmitter

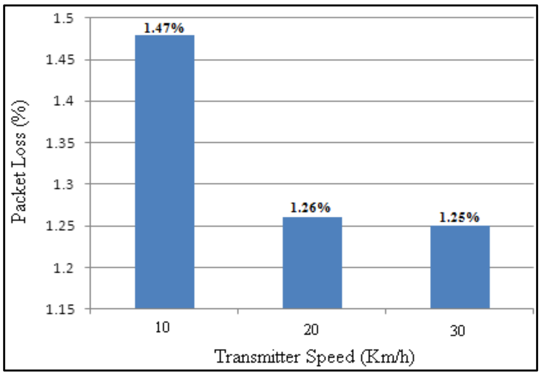

Figure 10. Packet loss rate against the speed of the bicycle

4. Conclusion

The research work on the training monitoring system grants a huge benefit during cyclist training to avoid over training and to have a high quality of training. The system enables the trainers to monitor and access the cyclist's training data at anytime and anywhere. Consequently, this improves the sport management system that leads to a better performance of the athletes. This work proposed a training monitoring system for cyclist that is designed to minimize the packet loss rate. The workability of the system architecture has been proven where it is able to function well in a real scenario with an acceptable rate of packet loss. It is shown based on the real scenario implementation that the angle of the transmitter has minimal impact to the packet loss rate. It has also been found that, more packets are lost during the data transmission when the bicycle is moving at a low speed of 10 km/hour, when compared to a high speed of 30 km/hour. Nevertheless, the data loss amount is around 1.47 percent, which is still minimum and acceptable. This proves that the proposed system is reliable and functions well even though the transmitter is moving at the high speed. The future work includes the investigation of multiple users/cyclists on the system's performance and comparison of the proposed system with the traditional cylist monitoring method.

Acknowledgements

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